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Nourishing Earth, Nourishing Ourselves Part 1: Linking Plant Diversity With the Health of Livestock and Humans

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Abstract

The foods we eat reveal the nature of our relationships with the places where we live. In this first of 3 papers, I highlight how the "taste of a place," or terroir, enables animals to meet their needs for nutrients and self-medicate by learning to eat nourishing combinations of foods in utero and early in life and by metabolically mediated flavor-feedback associations that alter food preferences as needs arise. When domestic herbivores learn to forage in landscapes with diverse mixtures of plant species, phytochemically rich diets bolster their health and protect them from diseases through antimicrobial, antiparasitic, anti-inflammatory, and immune-boosting properties. Human benefits accrue as livestock assimilate some phytochemicals and convert others into metabolites that enhance the flavors of meat and dairy and promote human health. During the past century, to our detriment, the flavors of meat, dairy, and produce became bland, while ultra-processed foods became irresistible as farmers and ranchers emphasized yield and transportability over taste and phytochemical and biochemical richness. At the same time, the food industry learned how to produce ultra-processed "foods" that hijack preferences. They do so by linking artificial flavors with metabolically mediated feedback from cells and organs in response to refined carbohydrates and sugars that, together with artificial flavors, obscure nutritional uniformity and undermine health. Fossil fuel-based food production has come at great costs ecologically, economically, and socially. With the uncertain availability and prices of fossil fuels a concern and the transition to clean energy a necessity, we have an opportunity to grow nutrient-rich foods in ways that nurture our relationship with life on Earth. Veterinarians can help people realize fossil fuels and climate change are part of an interwoven complex of food- and environment-related sustainability challenges that affect health and welfare. As voices for One Health, we must all come to value the role of plant diversity in creating homes, grocery stores, and pharmacies for all life below and above ground, while fixing carbon and reducing methane, thus helping to abate warming climates.

Introduction

Aldo Leopold began *A Sand County Almanac* with this statement: "There are some who can live without wild things, and some who cannot. These essays are the delights and dilemmas of one who cannot" (1). His book was a heartfelt account of how our growing detachment from nature was wreaking havoc on communities. Yet despite his eloquent pleas, the changes that fossil fuel-based human societies have fashioned since his death nearly 75 years ago are breathtaking. From the plundering of plants, animals, and Indigenous peoples during the era of 19th century manifest destiny in the United States to current times, humans have participated in the extinction of many of the plants and animals that make this planet habitable (2). We are now consumed by changes

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we wrought and consequences we did not foresee. Leopold concludes: "We abuse land because we regard it as a commodity belonging to us. When we see land as a community to which we belong, we may begin to use it with love and respect."

Envisioning land as a community to which we belong would transform our collective consciousness into one that respects, nourishes, and embraces our interdependence with life on Earth. To have any chance for success, such a rebirth must be built on love, a shared sense of community, and delicious, nutritious, healthy food. Through One Health, veterinarians can inspire and empower people to act because it is rewarding, enjoyable, hopeful, and delicious and because our collective actions will make a difference. In this series of 3 papers, I explore how we can cultivate life by using nature as a model for how to produce food; how we can move away from black-and-white opinions of what constitutes food for humans to more nuanced views of the sacredness of all life, plants and animals alike, and our dependence on them for nourishment; and how moving away from fossil fuels to clean energy will create opportunities to produce foods locally in ways that nurture relationships among soil, water, plants, herbivores, farmers, ranchers, and consumers. We can all become organic farmers and ranchers.

Three Interrelated Elements of Nutritional Wisdom

Nobody must tell bacteria, wild insects, fish, birds, or mammals how to eat, develop, and replicate. The same is true for wild and locally adapted domesticated herbivores who are challenged to select diets from hundreds of biochemically unique species of grasses, forbs, shrubs, and trees (3). Some species and plant parts are nutritious, and others are toxic. Individual plants can be nutritious or toxic depending on the time of the day, week, and season and the resources available in the plant's growing environment. Without nutritionists to formulate their rations or veterinarians and pharmacists to treat their illnesses, how do herbivores know which plants to eat to meet their needs for nutrients and medicines?

Palates link animals, including humans, with landscapes through 3 interrelated processes (3). First, to meet their needs for nutrients and medicines, animals must have access to a variety of wholesome foods (4–6). This balance is possible when wild and domestic herbivores learn to eat phytochemically rich mixtures of plant species but is less common when domestic herbivores are restricted to monoculture pastures or feedlot rations (4–6). The plant kingdom contains an estimated 10^5 to 10^6 chemically unique structures, with 5,000 to 15,000 structures per species, dwarfing all other taxonomic groups for specialized metabolites (7). Complex interrelationships among cells and organs and this diverse pool of compounds are increasingly recognized for how plants promote the health of animals (8–10). Phytochemicals bolster health and protect against diseases and pathogens in herbivores and humans through their antimicrobial, antiparasitic, anti-inflammatory, and immunomodulatory properties. Likewise, human health is enhanced as the biochemical richness of diets increases from single compounds such as eicosapentaenoic acid (EPA) or docosahexaenoic acid (DHA), to mixtures such as omega-3 fatty acids, to foods such as oily fish that contain hundreds of compounds in addition to omega-3 fatty acids, to combinations of wholesome foods such as meat and dairy, oily fish, and vegetables and fruits that contain tens of thousands of bioactive compounds (8).

Second, the female parent is a transgenerational link to landscapes in herbivores (3). Her knowledge of what and what not to eat, where and where not to forage, is essential for her offspring. Her influence begins in the womb (through flavors in her amniotic fluid of foods she eats) and continues after birth (through flavors in her milk of foods she eats) and when her offspring begin to forage (as a model for what to and not to eat) (3). Her influence is expressed epigenetically through changes in form (morphology), function (physiologically), and behavior (food and habitat selection), and chance plays a role during the development of organ systems (3). The combination of genes, environment, and chance ensures no individuals are ever alike. When not artificially weaned and separated, goats, sheep, and cattle live in extended families that combine the stability of the mother with the creativity of the offspring as they explore new foods and foraging locations (3, 11). For example, when nanny goats from different islands in the French West Indies were moved to an island with all the forages found on each of their home islands, the foraging behaviors of the adults did not change. Their offspring were influenced by both the mother and peers from other islands (12). Human eating behavior is similarly influenced by the mother and interactions among parents and young peers (3, 13).

Third, food preferences are mediated metabolically by feedback from cells and organ systems, including the gut microbiome, in response to nutritional and medicinal needs. During a meal of diverse foods, herbivores and humans introduce thousands of phytochemicals and biochemicals into the body in the forms of primary compounds (nutrients such as energy, protein, minerals, and vitamins) and the thousands of so-called secondary compounds (phytochemicals such as phenolics, terpenes, and alkaloids) that plants produce (3, 14). Changes in preference for foods due to post-ingestive feedback occur automatically (non-cognitively) each time food is eaten (15). The nature of feedback (satiety or malaise) depends on the match between a food's chemical characteristics and its ability to meet an animal's needs. These relationships—mediated by nerves, neurotransmitters, peptides, and hormones—are the basis for the wisdom of the body which enables animals to meet their needs for energy, protein, amino acids, minerals, and vitamins, and to self-medicate for maladies such as acidosis, toxicosis, and parasites (3, 4, 14, 16).

Food as Medicine

Insects, fish, birds, and mammals self-medicate to rectify illnesses. Even after 10,000 years of domestication, livestock can still learn to self-medicate when they have access to phytochemically rich forages (3). The same metabolically-mediated flavor-feedback associations that underlie preferences for foods with needed nutrients explain choices of medicinal plants by sick animals—ingestion of medicine at a proper dose transforms a sick animal into a state of health. Livestock use plants high in alkaloids, terpenes, and phenolics for their antimicrobial and antiparasitic properties (16). For example, compared with non-parasitized goats and sheep, parasitized animals prefer tannin-containing foods and forages. These differences disappear when parasite loads are eliminated, suggesting goats and sheep learn to self-medicate as a function of needs (17–19). The animals also learn to make multiple medicine-illness associations. When offered 3 medicines they have learned to use to alleviate illness, sheep select the medicine that assuages the condition they are experiencing: bentonite to relieve acidosis from eating too much grain, polyethylene glycol to alleviate toxicosis due to forages high in tannins, and dicalcium phosphate to ease toxicosis from excess oxalic acid (20).

These studies, along with many others reviewed in *Nourishment*, show the remarkable ability of the body to form flavor-feedback relationships under a range of nutritional, toxicological, and disease states (3). As this research shows, when given a choice of foods, livestock show an astonishingly refined palate, learning from past experiences to meet needs for nutrients and self-medicate as they nibble their way through the day eating a variety of grasses, forbs, and shrubs. While we use terms such as satiety and malaise to describe a continuum from wellbeing to illness, those terms do not begin to capture the nuances of flavor-feedback relationships among cells and organ systems and primary and secondary compounds. We know little about the communication between cells and organ systems as they interact with primary and secondary compounds in plants—all accomplished without a bit of thought from the host.

Historically, *Homo sapiens* relied on plants for medicine. Some maintain that the transition from an herbivorous to a more carnivorous diet roughly 2.6 million years ago increased exposure to pathogens and that strengthened plant-based self-medication by our ancestors, strategies already in place in primates (21). Researchers have recorded the use of medicinal plants by hominins from the middle of the Paleolithic Era, 1.65 million years ago (21). Cultures still have sophisticated, plant-based medical systems, add herbs and spices to food, and consume psychoactive plant substances harmful to helminths and other pathogens (21). Thus, medicinal plants played an equally important role in the story of human evolution, which has long emphasized hunting skills.

Nowadays, many medical professionals rely on synthetic drugs to treat human ailments and prevent production losses from disease and parasites in livestock. Reliance on drugs increases significantly for livestock fed low diversity, phytochemically impoverished diets as when animals are restricted to monospecific pastures or fed grain-based rations in feedlots (3, 5, 6). Conversely, livestock given access to phytochemically rich pastures and rangelands are healthier and more productive due to enhanced immune responses, fewer internal parasites, and less susceptibility to diseases (22). Besides their direct adverse impacts on parasites and microorganisms, phytochemicals provide prophylactic benefits through their antioxidant and immunomodulatory properties (22).

While the bulk of any meal is often composed of 3 to 5 plant species, herbivores may eat small amounts of 50 to 75 plant species daily (3). Historically, we did not appreciate the value of these minor parts of the diet (3). We now know the regular intake of a variety of phytochemically rich plants bolsters health and protects against diseases through antimicrobial, antiparasitic, anti-inflammatory, and immune-boosting properties (16, 22–25). Phenolics, terpenes, flavonoids, and volatile oils reduce oxidative stress and inflammation (26–28). Compared to a ryegrass diet, ewes fed ryegrass, chicory, plantain, red clover, and alfalfa had less oxidative and metabolic stress, and their lambs were less stressed and weighed more at birth (29). Animals fed phytochemically rich diets are far less reliant on antibiotic or antiparasitic drugs, and they have lower levels of morbidity and mortality than animals fed monotonous diets (29–31). They gain weight more efficiently and can reach slaughter weight nearly as quickly as animals in feedlots (16).

The outcomes of biochemical interactions depend on the dose. Some primary and secondary compounds can be toxic at high doses, but at proper doses they have health

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benefits (4). As a case in point, tannins were once thought to affect herbivores adversely but are increasingly recognized as beneficial in health and nutrition (32). Herbivores reduce internal parasites by eating plants high in tannins (33). Tannins alleviate bloat by binding to proteins in the rumen (34). They enhance nutrition by making protein unavailable for digestion until it reaches the more acidic abomasum, thus providing high-quality protein for absorption in the small intestines, which enhances immune responses and increases resistance to GI nematodes (35, 36). The increase in essential amino acids also improves reproductive efficiency (37). Dietary tannins can naturally reduce methane emission in ruminants, a key finding for ongoing efforts to reduce the adverse influence of livestock on global warming (38). Finally, tannins eaten in modest amounts by herbivores can improve the quality of their meat for human consumption (39, 40).

Livestock as Medicine for Human Health

Through managed grazing, livestock can be our partners in fostering diverse mixtures of plant species that make homes, grocery stores, and pharmacies for life below and above ground (3, 41–43). The benefits of plant-rich livestock diets to human consumers accrue as livestock assimilate some phytochemicals and convert others into metabolites that promote our health (30) (**Figure 1**). Historically, meat and dairy were not considered sources of phytochemicals, so their presence has been underappreciated in discussions of nutritional differences between grain- and forage-finished meat and dairy, which have focused on omega-3 fatty acids and conjugated linoleic acid. Yet many phytochemicals in forage-finished meat and dairy are in amounts akin to those in plant foods with anti-inflammatory, anti-carcinogenic, and cardioprotective effects (44,45). This expanded pool of phytochemicals and metabolites should be considered in understanding benefits to people, such as damping oxidative stress and inflammation linked with cancer, cardiovascular disease, and metabolic syndrome (9). On the other hand, diverse arrays of health-promoting phytochemicals are reduced or absent in meat and dairy from grain-fed animals, animals grazing monoculture pastures, or plant-based meat alternatives (39, 40, 44). Thus, monoculture–grass-fed animal meat and plant-based "meats" are not the same as meat from phytochemically rich landscapes regarding human or environmental health (30, 39, 40, 45, 46).

Figure 1

The health of livestock is promoted when they eat phytochemically diverse mixtures of plant species. The benefits to humans accrue when livestock assimilate some phytochemicals and convert others into metabolites that promote our health, akin to benefits realized by eating herbs, spices, vegetables, and fruits. These compounds dampen oxidative stress and inflammation linked with cancer, cardiovascular disease, and metabolic syndrome.

Studies of bison illustrate these points (43). Compared with bison in pens offered corn, meadow hay, and alfalfa hay, meat from bison finished on phytochemically rich rangelands has higher levels of compounds that benefit bison and humans, including polyphenols, tocopherols, carotene, and omega-3 fatty acids. While meadow hay and alfalfa hay add beneficial phytochemicals to their diet, pen-fed bison still have higher levels of less desirable compounds, including advanced glycation end-products, triglycerides, and short-chain acylcarnitines.

Due to the phytochemical richness of their diets and their higher levels of physical activity, bison on rangelands have improved markers of metabolic health. To use a human analogy, muscle from range-fed bison was like that of a healthy athlete, while that from pen-fed bison was more like that of a "couch potato," characterized by enhanced mitochondrial, glucose, and fatty acid metabolism (46). Greater mitochondrial oxidative enzyme levels in animals eating phytochemically rich diets are analogous to those in fit athletes (45). Equally important, bison experience less stress when they forage on rangelands as opposed to living in pens, which further substantiates findings regarding their metabolic health (3, 45).

The effects of eating meat or dairy from animals foraging on phytochemically rich diets are partially due to the ability of phytochemicals to reduce inflammation (39, 40). People have much lower levels of inflammatory markers when they eat meat from animals foraging on phytochemically rich landscapes as opposed to grain-finished in feedlots (47). Low-grade systemic inflammation—characterized by elevated levels of cytokines such as interleukin-6, tumor necrosis factor-alpha, and C-reactive protein—contributes to metabolic disease, type II diabetes, heart disease, cancer, and arthritis (48). Notably, cytokines respond within a meal, with increasing odds of developing maladies when meals that generate high inflammatory responses become dietary habits, which is now the case with Western diets (49, 50).

In traditional pastoral communities, humans experience phytochemically rich meat, milk, and butter as flavors that smell and taste of the many wild herbs that animals graze freely across the plains (3, 51). As I will elaborate on in the following papers, this "taste of place" is the vital connection, which most humans have broken, between local community, local ecosystem, and local food production. Consider as well, if a pathogen spreads through a locality, domesticated herbivores can self-medicate on the most appropriate compounds for their wellbeing, which may also be passed to humans. By eating locally produced meat and dairy from livestock on phytochemically rich pastures, we would not only be keeping ourselves topped up with antimicrobials but keeping ourselves up to date with local pathogens before "outbreaks" emerge. While this may not matter in a globalized world, if we are in the process of returning to more localized food production systems, conceivably to reduce our carbon footprints in the face of changing climates and due to uncertainty in the cost and availability of fossil fuels, this "local plant for local pathogen" scenario may become more critical. As plants adapt their antimicrobials to local pathogens, surely eating locally produced meat becomes more desirable.

Currently, in the United States only 4% of beef calves spend their entire lives eating phytochemically rich mixes of plants on pastures and rangelands where they were born and reared. The other 96% of calves are weaned at 7 to 8 months of age and fattened in feedlots, often under conditions that violate freedoms of animal welfare: freedom from fear, distress, discomfort, pain, injury, and disease. They are moved from familiar (mother, peers, home pastures) to unfamiliar (feedlots) locations, which causes fear and distress (52). Though individuals differ in food preferences, they cannot self-select their diets, which violates their freedom to express normal behavior, maintain health, and avert discomfort and disease (53). They dislike any food eaten too often or in excess, yet they are fed daily the same ration so high in grain they experience nausea which causes food aversions, discomfort, stress, and distress (23, 52–55). These practices cause animals in feedlots to suffer various maladies, including liver abscesses, chronic acidosis, oxidative and physiological stress, and other metabolic diseases akin to people with metabolic syndrome, characterized by muscle mitochondrial dysfunction, oxidative stress, and elevated levels of blood glucose, insulin, and cortisol (47). Animals are sustained on antibiotics to counter the effects of phytochemically poor diets and lack of exercise on morbidity and mortality. This overuse in feedlots helped to create antibiotic resistance.

During the past century, the increasing lack of phytochemical and biochemical richness caused the flavors of meat, dairy, vegetables, and fruits to become bland while ultra-processed foods became irresistible. Agricultural practices increased yields of crops at the expense of phytochemical richness; amounts of phytochemicals declined 10% - 50% in 43 fruits, vegetables, and grains from 1950 to 1999 (56, 57). At the same time, the food industry learned to mass-produce foods that link synthetic flavors with feedback from energy-rich compounds that obscure nutritional uniformity and diminish health (58). Thus, the roles plants

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and animals once played in nutrition have been usurped by processed foods that are altered, fortified, and enriched in ways that can adversely affect appetitive states and food preferences (6). People now over-consume nutrient-poor, ultra-processed foods, which account for over half of caloric intake in many countries (59). As with humans, our pets are overfed and undernourished from eating ultra-processed foods formulated for the "average" individual, analogous to livestock fed total-mixed rations in feedlots (60). So-called lifestyle diseases far surpass death rates from infectious diseases. Increased risk of diseases, often attributed to high intake of red meat in epidemiological studies, is associated with eating an ultra-processed diet but not with eating phytochemically and biochemically rich assortments of meat, dairy, and produce (61, 62). We can decrease demand for ultra-processed foods by re-creating cultures that can grow and combine nutrient-rich plant and animal foods into meals that nourish and satiate (6).

Veterinarians can help their clients realize fossil fuels and climate change are part of a complex and interwoven collection of food-related sustainability challenges that affect health and welfare. As I will discuss in the following papers in this series, with uncertainty in the costs and availability of fossil fuels a reality and the transition to clean energy a necessity, we may all need to grow and rely upon nutrient-rich foods for nourishment and medicine.

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